SIMULATION MODELING AND ANALYSIS OF OVERNIGHT VISITOR USE OF THE YOSEMITE WILDERNESS

Final Report to National Park Service, Yosemite National Park, El Portal, California

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EXECUTIVE SUMMARY

INTRODUCTION AND OBJECTIVES

In response to overuse in the Yosemite wilderness, a mandatory permit system was implemented in 1972. Subsequently, the wilderness was divided into 53 management zones, and an overnight camping capacity was established for each. In order to minimize the probability that use exceeds zone capacities, without imposing excessive regulation on users once they enter the wilderness, a trailhead quota system was implemented in 1977. Trailhead quotas were derived from permit data and a simulation model that related zone use to trailhead use. However, changes in the characteristics of wilderness visitors could change the effectiveness of the quota system in preventing overuse, but no systematic study of Yosemite wilderness use has been conducted since the 1970s.

The goal of this study was to assess current use of the Yosemite wilderness. Because of the complexity of interaction among factors that determine use in an individual zone on an individual night ("zone-night"), a computer simulation model, populated with current data on visitor characteristics, is the best way to accomplish this goal. Objectives were:

1. Quantify wilderness visitor characteristics;
2. Compare characteristics of current wilderness users with those of the 1970s;
3. Construct, populate and validate a wilderness use simulation model that
    a. incorporates observed itinerary deviation characteristics,
    b. predicts means and percentiles of use at the zone-night resolution, and
    c. includes the effect of wilderness use originating outside of Yosemite;
4. Employ the simulation model to
    a. quantify current use at the zone-night and annual scales by source,
    b. estimate probabilities of capacity exceedance at the zone-night scale,
    c. quantify the dependence of zone use on trailhead use, and
    d. find a trailhead assignment scenario that achieves "no exceedance"; and
5. Identify both the most heavily used zones and trailheads and the zones and trailheads that have the greatest potential to absorb increased use.

METHODS

We constructed a stochastic simulation model of wilderness use with ExtendSim OR software. Distributions of party size, trailhead selection, and trip date were created directly from the 2010 wilderness permit database, using information from all 14,497 parties that started trips during the 1 May to 30 September season and intended to spend at least one night in the Yosemite wilderness. Trip date was assigned deterministically in the model; all other characteristics were assigned or simulated stochastically. Party size, trip date, and trailhead were the only attributes assigned at the initiation of a simulated trip. Trailheads were assigned randomly by an algorithm that filled trailheads in order of popularity

according to observed probabilities of trailhead selection. On average, parties that were assigned a trailhead at quota were reassigned the next most popular trailhead that was available. Instead of creating a fixed set of travel itineraries, travel route and trip duration for each party were created dynamically according to a zone transition probability matrix that was created from the permit database. Additional transition matrices and user attribute distributions were created for Yosemite wilderness use that originated at surrounding U.S. Forest Service (USFS) trailheads.

We surveyed a random sample of 1,123 wilderness visitors to quantify their deviation from intended itineraries and then applied the observed rates of spatial deviation stochastically in the model. Temporal deviation was modeled by changing the odds of exiting the wilderness in the transition matrix, without changing the relative transition probabilities among the zones. The factor by which exit odds were adjusted was determined by requiring mean trip duration produced by the model to match our estimate of mean trip duration of actual users. This estimate was produced by adjusting intended trip duration of all trips in the permit database by the deviation characteristics observed in the sample. The odds adjustment factor was the only model parameter determined by calibration; all other parameters were determined directly from the database or sample.

We used statistical model verification and validation methods to ensure that model algorithms were implemented correctly and that intended use at the zone-night resolution matched observed values. Based on behavior of variance in model outputs, we determined that 1,000 season-long replicates were adequate to provide accurate estimates of output, and we based all of our results on 1,000 replicates. We used the model to simulate current conditions, find a trailhead redistribution scheme that lowered use in the most heavily used zones, and determine the effects of filling all trailhead quotas on every day. The end user of the model can easily adjust the trailhead quotas and the number of parties that start on each day of the season to investigate other situations.

RESULTS

Mean intended trip duration in 2010 was 2.48 nights, which was significantly lower than the value of 2.94 observed in the 1970s. Mean party size was 2.92, which was significantly lower than the value of 3.26 observed in the 1970s. However, the permit itinerary adherence rate of 34.2% was not significantly different than the rate of 37.7% observed in the 1970s. In 2010, 36.2% of parties deviated temporally from their intended itineraries, and 54.4% deviated spatially. Spatial and temporal deviations were not independent; 25.2% of all parties deviated both spatially and temporally. The mean temporal deviation was a decrease of one night in trip duration. Trips were shortened at a rate of 0.42 nights per night the party intended to spend in the wilderness, and this rate was not significantly different than the value of 0.33 estimated in the 1970s. When applied to all permitted parties, temporal deviation lowered mean trip duration to an estimated actual value of 2.12 nights. Taken together, spatial and temporal deviation reduced the

season-total estimate of Yosemite-derived use 14.7%, from 105,571 visitor nights based on intended itineraries to 89,997 based on simulations that incorporated deviation. Use from outside of Yosemite contributed an additional 10,010 visitor nights (Table E1), thereby comprising 10% of total use, compared with an estimated 4% in the 1970s. About 0.5% of total season-long use occurred in frontcountry backpacker camps.

Table E1. Mean annual use and bounds on the middle 95 percentiles of use, by source.

Source	Mean Annual Use (visitor nights)	% of Use	2.5th percentile	97.5th percentile
Yosemite trailheads	89,997	90.0%	88,255	91,740
Bridgeport USFS	3,010	3.0%	2,517	3,504
Other USFS	6,235	6.2%	5,707	6,764
Pacific Crest Trail	765	0.8%	727	802
TOTAL	100,007	100%	98,121	101,895

The eight most heavily used zones accounted for 43.6% of total use (Table E2), compared with 51.1% in 1973 and 36.9% in 1979. This group includes five of the eight most heavily used zones in the 1970s. Snow Creek, May Lake, and Yosemite Creek were in the top eight in 2010 but not in the 1970s; all of these are adjacent to trailheads. Mean use in each of Sunrise Creek, Snow Creek, Glen Aulin, and May Lake exceeded capacity on at least one night. Together, they accounted for 50 zone-nights on which mean use exceeded capacity and 203 zone-nights on which capacity exceedance probabilities were greater than 20%. In addition, capacity exceedance probabilities in Vogelsang were greater than 20% on 34 nights. Use originating outside of Yosemite had relatively little effect on any single zone except Lyell Canyon, where 22.5% of use originated outside of the park.

Table E2. Use (visitor nights) in the eight most heavily used zones. The Relative Use Index is percent of total use due to that zone divided by its percent of capacity. Values greater than 3 indicate at least a 20% chance that use exceeds capacity on more than one night.

Code	Zone	Capacity	YOSE use	%YOSE use	Total use	% Total use	Relative Use index
59	Little Yosemite Valley	150	7679	8.53%	7922	7.92%	2.22
68	Yosemite Creek	100	6964	7.74%	6973	6.97%	2.93
72	Lyell Canyon	125	4892	5.44%	6313	6.31%	2.12
66	Sunrise Creek	50	5547	6.16%	5807	5.81%	4.88
67	Snow Creek	50	4595	5.11%	4605	4.61%	3.87
81	Glen Aulin	50	4003	4.45%	4122	4.12%	3.46
63	Vogelsang	50	3779	4.20%	3950	3.95%	3.32
75	May Lake	50	3864	4.29%	3872	3.87%	3.25

By lowering trailhead quotas at nine of the most popular trailheads and redistributing an average of 3,575 parties from these trailheads to the least popular trailheads in the park, we simulated a condition in which mean use exceeded capacity on only one zone-night. The probability that use exceeded capacity was greater than 30% in only eight out of 8,109 possible zone-nights, compared with 134 zone-nights under current conditions. When every trailhead is filled to quota every day, a maximum of 1,196 parties per day are allowed into the wilderness, equating to a mean of 2,260 visitor nights per day. This rate of use is only 54% of the total zone capacity of 4,200, yet travel patterns are such that even in absence of temporal or spatial preference for trailheads, use in many zones greatly exceeds capacity. Under maximum allowable use, zones with the greatest mean use, relative to capacity, are Bridalveil Creek, Snow Creek, and Yosemite Creek. Use exceeds 150% of capacity in Snow Creek and Yosemite Creek on nearly every night. These two zones are among the most heavily used under current conditions as well. On the other hand, there are many zones in which use never exceeds capacity, even with every trailhead full on every night.

Under current conditions, most zones receive the majority of their use from only a few trailheads. Every zone except Washburn Lake and Twin Lakes receives at least 20% of its use from a single trailhead, and 18 zones receive over 50% of their use from a single trailhead. Part of this observed zone use-trailhead relationship is determined by visitor preference in time and space. The zone use-trailhead relationship produced by filling each trailhead to quota on each day removes spatiotemporal visitor preference for trailheads and results in the inherent relationship between zone use and trailhead of origin that is determined by the geography of the park, the physical capabilities and short-term behavior of wilderness users in selecting routes and camping locations, and the trailhead quotas themselves. Under this "true" relationship, the distribution of use across trailheads is more uniform than that currently observed, and comparison between the true zone-trailhead relationship and the current relationship allows identification of the trailheads that contribute the most to visitor use relative to their quota (e.g., Mirror Lake to Snow Creek) and those that contribute the least relative to their quota (e.g., Westfall).

MANAGEMENT IMPLICATIONS

Our results have three primary implications for management.

1. **Adjustment of permit data.** Deviation from intended itinerary reduces use levels about 14% from those estimated from raw permit data. Thus, management actions made to lower zone use that are informed strictly by use figures derived from permit data are likely to be overly conservative. On the other hand, about 10% of total zone use originates from outside of the park. Based on current conditions, a procedure for estimating actual use from the permit database, without having to go through the entire simulation procedure, is to first reduce permit-derived use estimates by 14%. Then, increase the resulting use in Lyell Canyon by 30% and use

in all of the other zones by about 1.5%. This method can be applied at the resolution of zones or zone-nights and will result in a better estimate of actual use conditions than simply using the raw permit data.

2. **Effects of shorter trip durations.** Although shorter trip durations do not necessarily lead to zone capacity exceedances, they do lead to a greater fraction of total use in zones that are readily accessible from trailheads. Snow Creek, May Lake, and Yosemite Creek are among the eight most heavily used zones today, but none were in the top eight in the 1970s, providing some evidence that a preference for shorter trips may be leading to increased use in some zones. Redistributing some of these shorter trips to parts of the park that receive less use could lower capacity exceedance probabilities under current use levels and trip characteristics.
3. **Effectiveness of trailhead quotas.** As detailed in lengthy analysis in the full report, we conclude that the inherent relationship between zone use and trailhead use has probably changed very little since the inception of the quota system, given that this relationship is based primarily on geography, physical capabilities of wilderness users, and the quotas themselves. The zone-use trailhead relationship based on actual use patterns may have changed somewhat due to changes in user preferences, but even with preference removed, geography dictates that most use in most zones will come from a relatively small number of trailheads. Thus, the original quota system remains a viable basis from which to determine future management. More importantly, our "no-exceedance" solution illustrates one of a theoretically infinite number of ways in which current use can be redistributed to lower-use areas in the park to achieve substantially lower probabilities of capacity exceedance without changing overall use, temporal distribution of use, or any other party or trip attribute. Therefore, we have shown that not only is the trailhead quota scheme a viable approach to managing use in wilderness zones but more importantly that a specific trailhead quota scheme exists that reduces capacity exceedance in Yosemite. This scheme can serve as a starting point for developing others that can achieve management objectives under socially acceptable conditions.